

Integrated Design Software Predicts the Creep Life of Monolithic Ceramic Components

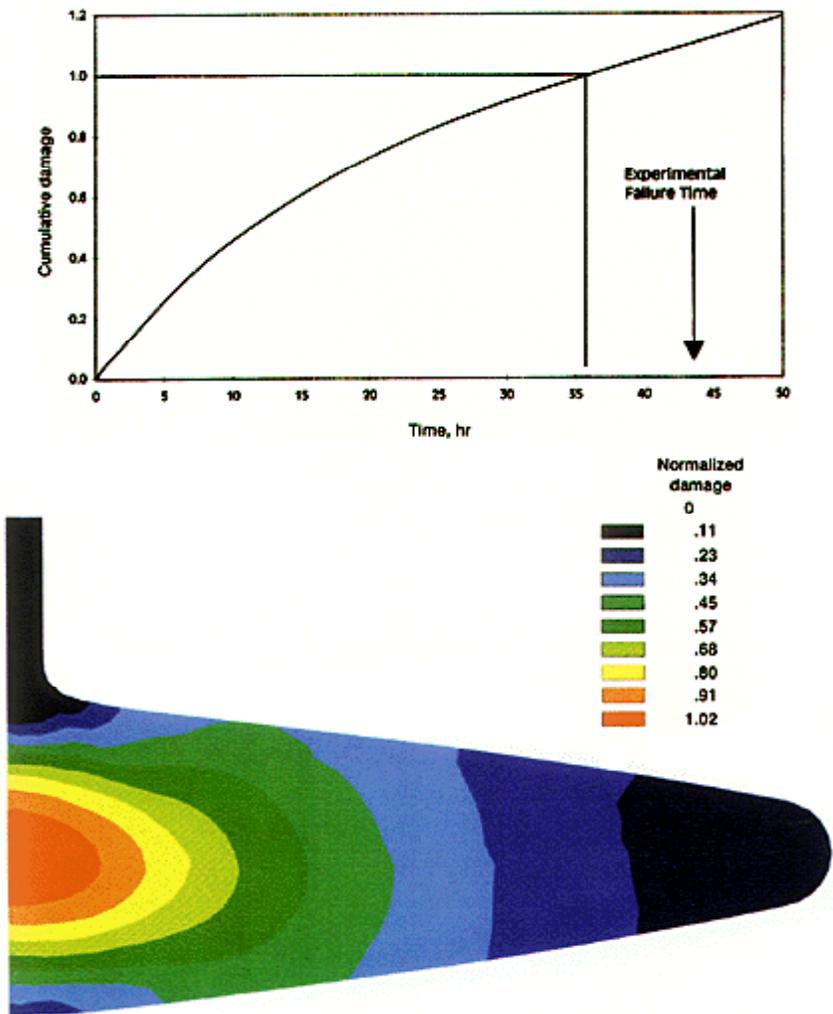
Significant improvements in propulsion and power generation for the next century will require revolutionary advances in high-temperature materials and structural design. Advanced ceramics are candidate materials for these elevated-temperature applications. As design protocols emerge for these material systems, designers must be aware of several innate features, including the degrading ability of ceramics to carry sustained load.

Usually, time-dependent failure in ceramics occurs because of two different, delayed-failure mechanisms: slow crack growth and creep rupture. Slow crack growth initiates at a preexisting flaw and continues until a critical crack length is reached, causing catastrophic failure. Creep rupture, on the other hand, occurs because of bulk damage in the material: void nucleation and coalescence that eventually leads to macrocracks which then propagate to failure. Successful application of advanced ceramics depends on proper characterization of material behavior and the use of an appropriate design methodology. The life of a ceramic component can be predicted with the NASA Lewis Research Center's Ceramics Analysis and Reliability Evaluation of Structures (CARES) integrated design programs. CARES/CREEP determines the expected life of a component under creep conditions, and CARES/LIFE predicts the component life due to fast fracture and subcritical crack growth. The previously developed CARES/LIFE program has been used in numerous industrial and Government applications.

The advent of new techniques in ceramic processing technology has yielded a new class of ceramics that are highly resistant to creep at high temperatures. Such desirable properties have generated interest in using ceramics for turbine engine component applications where the design lives for such systems are on the order of 10,000 to 30,000 hr. These long life requirements necessitate subjecting the components to relatively low stresses. The combination of high temperatures and low stresses typically places failure for monolithic ceramics in the creep and creep-rupture region of a time-temperature-failure mechanism map.

CARES/CREEP, an analytical methodology in the form of an integrated design program, was developed for predicting the life of ceramic structural components subjected to creep rupture conditions. This methodology employs commercially available finite element packages and takes into account the transient state of stress and creep strain distributions (stress relaxation). The creep life of a component is discretized into short time steps during which the stress distribution is assumed constant. The damage is calculated for each time step on the basis of a modified Monkman-Grant creep rupture criterion. The cumulative damage is subsequently calculated as time elapses in a manner similar to Miner's rule for cyclic fatigue loading. Failure is assumed to occur when the normalized cumulative damage at any point in the component reaches unity. The corresponding time is the creep rupture life for that component.

Benchmark problems of creep life prediction for ceramic components under multiaxial loading have demonstrated the CARES/CREEP program. Analysis of a spin disk, which was a part of an AlliedSignal Inc. program to develop and demonstrate life-prediction methods for ceramic components of advanced vehicular engines, revealed failure mechanisms that were a combination of creep and slow crack growth. The second problem was a silicon nitride notched tensile specimen, which was analyzed as a part of the Saint Gobain-Norton advanced heat engines applications program. When the maximum damage in the notched tensile specimen versus time is plotted, failure is expected to occur when the damage is equal to 1. The predicted failure time was 37 hr, whereas the actual failure time was 44 hr, demonstrating a conservative prediction.



Top: Maximum cumulative damage versus time for a silicon nitride notched tensile specimen. Bottom: Cumulative creep damage distribution for a silicon nitride spin disk.

The CARES/CREEP code predicts the deterministic life of a ceramic component. Future work involves the role of probabilistic models in this design process. The complete package will predict the life of monolithic ceramic components by using simple uniaxial creep laws to account for multiaxial creep loading. The combination of the

CARES/CREEP and CARES/LIFE codes gives the design engineer the tools necessary to predict component life for the two dominant delayed-failure mechanisms.